IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
Washington, D.C., United States of America

NON-PROVISIONAL UTILITY PATENT APPLICATION

For:

A METHOD AND CIRCUIT FOR REPETITIVELY FIRING A FLASH LAMP OR THE LIKE

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Attorney Docket No.: ZB999/04005

CROSS-REFERENCE TO RELATED APPLICATIONS

Not applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not applicable.

REFERENCE TO A "SEQUENTIAL LISTING," A TABLE, OR A COMPUTER PROGRAM LISTING APPENDIX SUBMITTED ON A COMPACT DISC

Not applicable.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to electrical circuits for repetitively firing a flash lamp or the like.

2. Description of Prior Art

Arc lamps generally have a pair of electrodes between which an arc can be created by applying a voltage potential between the electrodes which is greater than the breakdown voltage of the medium between the electrodes.

Flash lamps generally have a pair of electrodes sealed in a tube containing a gaseous medium which is normally non-conductive, but which can be externally ionized to become conductive. The electrodes are connected to an energy storage device, such as a capacitor, which can be charged to a high energy level. The gaseous medium may be ionized and, thus, become conductive, by briefly applying a high voltage to a trigger wire wrapped around the lamp. Thus, the energy stored in the capacitor will discharge through the flash lamp as a high current density arc which creates a pulse of high energy electromagnetic radiation, such as visible light or ultraviolet radiation.

The gaseous medium will remain conductive as long as current continues to flow, even after the voltage is removed from the trigger wire. However, the current will cease flowing when the voltage across the electrodes falls to a level defined for this description as the "self extinguishing voltage" or "discharge resting potential" of the flash lamp. Typical self extinguishing voltage values fall in the 100 - 300 volt range. Shortly after the current stops flowing, the gaseous medium will de-ionize and become non-conductive again.

Additionally, for the purposes of this description, the period of time for the firing of the flash lamp from the ionization to the de-ionization of the gaseous medium is defined

as the "discharge time". Typical discharge times will fall in the 30 - 200 microsecond range.

Pulsed radiation has been found to be useful in tanning, treating human skin diseases, curing plastics, and photochemical processes, among other uses. Thus, it is desirable to repetitively "fire" flash lamps to generate such pulsed radiation.

However, the gaseous medium of the flash lamp must de-ionize before the capacitor can be recharged for another cycle. If the flash lamp fails to de-ionize before charging voltage greater than the self extinguishing voltage is applied to the capacitor, the lamp will not de-ionize and current will continue to flow through the lamp producing "afterglow" or continuous current flow through the gas. Afterglow results in large continuous current flows resulting in rapid overheating and system failure.

In the past, pulsed operation of a flash lamp required a separate circuit for holding the charging voltage from the capacitor until the gas was fully de-ionized in each flash cycle. As the flash energy and cycle frequencies increase, electromagnetic interference and timing issues cause the complexity and expense of such separate circuits to also increase.

BRIEF SUMMARY OF THE INVENTION

It is an object of the present invention to provide a simple method and circuit for repetitive firing of the flash lamp or the like.

While the disclosed invention is directed primarily to flash lamps, one of skill in the art will recognize that the invention may be applied to other electrical devices by controlling the discharge and recharge timing of the energy storage device to deliver similar pulses of high current density energy.

These and other objects are achieved through a method and circuit for repetitively firing a flash lamp.

The method has the steps of providing a periodic power supply signal having a minimum voltage below the flash lamp de-ionizing voltage threshold, providing a means for storing energy, such as an energy storage circuit, across the electrodes of the flash lamp and across the power supply, charging the energy storage means to the peak voltage of the power supply signal, firing the flash lamp when the power supply signal is below the de-ionizing voltage threshold, and repeating the charging and firing steps repeatedly.

The circuit has a means for storing energy, such as an energy storage circuit, having inputs for connection to a periodic power supply signal and connected across the electrodes of the flash lamp, a means for triggering the flash lamp, such as a triggering circuit, and a means for detection when the voltage of the periodic power supply signal falls below a predetermined level, such as a voltage detection circuit, where the means for detecting is operative to trigger the means for triggering, thereby firing the flash lamp when the periodic power supply voltage signal is below the predetermined level.

Alternate embodiments of the method and circuit add a means for interrupting or quenching the current flow, such as a

current interruption circuit, to the flash lamp when the voltage across the energy storage means fall to a predetermined level.

Finally, the principles of the invention may be extrapolated to other electrical devices by controlling the discharge and recharge timing of the energy storage device to deliver similar pulses of high current density energy.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

Figure 1 show a block diagram of a method and circuit for repetitively firing a flash lamp according to the present invention.

Figure 2 shows a representative periodic power supply signal as might be used with the present invention.

Figure 3 shows a timing diagram of the electrical events within a flash lamp circuit according to a first embodiment of the present invention.

Figure 4 is an electrical schematic diagram of a flash lamp circuit according to a first embodiment of the present invention.

Figure 5 shows an alternate charging configuration.

Figure 6 is an electrical schematic diagram of a flash lamp circuit according to a second embodiment of the present invention.

Figure 7 shows a timing diagram of the electrical events within a flash lamp circuit according to a second embodiment of the present invention.

Figure 8a shows a timing diagram of a current flow during discharge of a flash lamp circuit according to a first embodiment of the present invention.

Figure 8b shows a timing diagram of a current flow during discharge of a flash lamp circuit according to a second embodiment of the present invention.

Figure 9 shows a graph of the spectral output of the flash circuits according to the first and second embodiments of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

a. First Embodiment

Figure 1 is a block diagram of a first embodiment of the present invention having a power supply having a periodic voltage signal, a means for storing energy, such as an energy storage circuit, attached to the power supply, a flash lamp attached to the energy storage means, a means for detecting a low voltage signal, such as a voltage detection circuit, which samples the power supply signal, and a means for triggering the flash lamp, such as a flash lamp triggering circuit, which is responsive to the low voltage detection means to trigger the flash lamp.

Figure 2 shows a sample periodic voltage signal 10 of a power supply. The voltage signal 10 has a minimum voltage V_M. Also marked is a sample flash lamp self extinguishing voltage V_{SE}. The minimum voltage V_M of the power supply of the invention must be less than the flash lamp self extinguishing voltage V_{SE}.

Additionally, the period of time that the voltage signal 10 is less than the flash lamp self extinguishing voltage V_{SE} must be greater than discharge time of the flash lamp.

Advantageously, the embodiments of the invention described herein may use standard 115 volt or 230 volt, 60 hertz alternating current as the primary power source, provided to the primary side of a transformer, for stepping up the voltage of the signal to approximately 2000 volts for firing the flash lamp. Thus, the period of time that the voltage signal 10 is less than a typical flash lamp self extinguishing voltage of 100 - 300 volts will be substantially greater than the discharge time of 30 - 200 microseconds for a typical flash lamp. However, one of skill in the art will recognize that the invention will perform with any periodic signal meeting the requirement that the minimum voltage V_M is less than the self extinguishing voltage V_{SE}.

Returning now to Figure 1, the AC power supply charges the energy storage means. When the means for detecting a low voltage signal detects that the power supply signal 10 is less than the flash lamp self extinguishing voltage V_{SE}, it activates the means for triggering the flash lamp, which fires the flash lamp, thereby discharging the energy storage means while the power supply signal 10 remains below the flash lamp self extinguishing voltage V_{SE}. Thus, the gaseous medium of the flash lamp will de-ionize prior to the return of the power supply signal 10 and the voltage across the energy storage device to a level above the de-ionizing voltage threshold, preventing afterglow and the problems associated therewith.

Thus, Figure 3 shows the electrical events within a representative flash lamp during a discharge. The voltage 12 across the lamp electrodes peaks at approximately 2000 volts. When the trigger voltage ionizes the lamp, resistance 14 falls close to zero for about 100 microseconds. The current 16 increases to several thousand amperes for a similar time frame. The voltage 12 falls to about 200-300 volts. The power supply voltage signal 18 does not rise above this 200-300 volt discharge level until the lamp has fully de-ionized and returned to full resistance.

Figure 4 shows a representative circuit according to the first embodiment of the present invention wherein the means for storing energy is a capacitor C1. The means for detecting a low voltage signal is a voltage sensing circuit. The means for triggering the flash lamp is shown as the circuit elements SCR, capacitor C2, and trigger coil T1. The flash lamp medium is xenon at less than one atmosphere with a minimum discharging voltage of 1000 volts.

Figure 5 shows an alternate charging arrangement wherein one side of the power supply voltage signal, such as the high power secondary winding of a transformer, is connected to a node between two capacitors, while the other side of the power supply voltage signal is connected a forward biased diode that charges one capacitor to a positive voltage and also to a reverse biased diode that charges the other capacitor to a negative voltage.

A low power secondary winding of the transformer (not shown) can be used to charge a small capacitor C2 for discharge into the trigger coil T1 that ionizes the flash lamp. To operate the linear xenon lamp at an average power of 600 watts, each of

60 flashes per second must receive 10 joules. Using the alternate charging arrangement, the two storage capacitors C1 are charged to positive 1000 volts and negative 1000, respectively, for a total potential across the flash electrodes of 2000 volts. The trigger coil T1 transforms the trigger pulses of 10-15 millijoules from a 0.22-microfarad capacitor C2 to 15,000-25,000 volts to ionize the lamp 60 times per second. The pulse is initiated from the voltage sensing circuit when the power supply voltage signal approaches zero. The threshold of this voltage sensing circuit is adjusted to ensure that the light pulse will extinguish before the power supply voltage signal exceeds the self-extinguishing voltage of the lamp. With the SCR in the off state and the flashlamp de-ionized, the next voltage cycle will recharge the storage capacitors without "afterglow."

b. Second Embodiment

In a second embodiment, as shown in Figure 6, additional circuitry in series with the flash lamp is used to interrupt the flash prior to the natural decay of the storage capacitors C1. The interruption is introduced at a specified voltage. The current interruption reduces the current long enough to allow the gas to de-ionize and become highly resistive. This in turn allows the alternating current to re-cycle through recharging the capacitors for a subsequent discharge. This allows the amount of energy released from the storage capacitors C1 to be tightly controlled. Larger capacitors may be charged to a higher energy level, resulting in extended or prolonged peak current densities.

As shown in Figure 6, the current interruption circuitry of the second embodiment is comprised of a high current bipolar MOSFET operated by a voltage comparator. The set point of the voltage comparator is set by Vref and VR1. The voltage comparator monitors the storage capacitor C1 during the flash and sends a signal to the bipolar MOSFET when the voltage drops below the set point. This signal turns off the MOSFET and interrupts the current flow to the lamp, which forces the lamp to de-ionize well before the storage capacitors C1 have completely discharged.

Figure 7 shows the electrical events within the flash lamp circuit according to the second embodiment of the invention. The voltage across the lamp 22 peaks at approximately 2250 volts. When the trigger voltage ionizes the lamp medium, the lamp resistance 24 falls close to zero for about 50 microseconds. Initially, the current 26 increases to several thousand amperes. The bipolar MOSFET interrupts the current when the voltage drops below the set point, which is about 1500 volts. The power supply voltage signal 28 does not rise above this 1500 volt discharge level until the lamp has fully de-ionize and returned to full resistance.

c. Relationship between Current Density and Spectral Output

Another important perspective is the relationship between current density and spectral output. Typically as current density reaches 7000 amps/cm^2 the light emitted becomes more ultraviolet. Superimposed upon this is the electron shell architecture for each as, causing some to have unique and specific responses to subtle changes in the current density. The

general formula for energy within a capacitor that can be discharged into a gas lamp states

$$\text{Energy} = 1/2(CV^2)$$

Where C represents capacitance and V represents the charging voltage. This formula represents the situation where the capacitor discharges to the point where the gas plasma extinguishes. The special situation develops when a device is introduced to stop the discharge at a certain voltage. The energy formula becomes

$$\text{Energy} = 1/2C[(V_2)^2 - (V_1)^2]$$

When the difference between V_2 and V_1 remains constant then the difference of the squares increases as the voltages increase. For example the difference between 1 and 0 volts and between 21 and 20 volts remains 1 volt. But the difference of the squares is 41. By increasing the charging voltage V_2 and the size of the capacitor C1, the pulse duration may be shortened while also maintaining or increasing the energy. This results in increased current density and shorter pulse duration. The second embodiment of the invention demonstrates this effect.

Figures 8a and 8b show representative current flows of embodiment 1 and embodiment 2, respectively. As shown, interrupting the discharge current allows the shape of the current discharge to be molded to increase and prolong the average current density during the light pulse, providing the benefit of targeting the response desired from flash lamp, e.g. specific spectral output.

Figure 9 shows a representative spectral output of the embodiments of the invention. The spectral output of the second

embodiment 30 shows an increase in the overall amount of ultraviolet light and selective peaks in this region over the spectral output of the first embodiment 32.

d. Increased Current Density with Other Electrical and Electromechanical Devices

Similar increases in current density can be realized with other electrical and electromechanical devices. One example of such a device is a motor. In a motor, the force generated is proportional to the current density of the power supply. A sustained higher current density will transfer energy more efficiently. Thus, multiple timing circuits and capacitors may be utilized to provide smoother current transfer and to generate more efficient electromotive force.

Extrapolating from the flash lamp circuit embodiments, the invention employs a first detection circuit for determining when the power supply voltage signal falls below a first predetermined value, which is selected to provide time for the energy storage means to discharge while the power supply voltage signal is low. Thus, the discharge may be completed before the power supply voltage starts recharging the energy storage means. Additionally, the invention employs an interrupting means to stop the discharge prior to full discharge of the energy storage means. A second detecting circuit is used to sense when the voltage across the energy storage means falls below a second predetermined value. Thus, by controlling the discharge and recharge timing of the energy storage device, the invention will produce pulses of high current density energy.

Multiple circuits may then be synchronized to provide power waveforms required to operate such electromechanical devices at variable speeds or as otherwise desired.

The detail description of the embodiments contained hereinabove shall not be construed as a limitation of the invention, as it will be readily apparent to those skilled in the art that design choices may be made changing the configuration without departing from the spirit or scope of the invention.